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Research Article

Optimization of CO Emission of CIDI Engine Fuelled with Jatropha Curcas Methyl Ester using Taguchi Method

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Abstract

In order to meet the current and estimated future global energy consumption and to reduce the hazardous environmental pollution due to hefty usage of fossil fuels in the fields of transportation and industries foster the research on renewable energy sources. The previous research studies revealed that plant based oils, waste cooking oils, and animal fats can be used as biodiesel to reduce the dependence on fossil fuels, to reduce the foreign fuel imports, lower the green gas emissions and uplift the rural economies. The objective of the present research study is to evaluate the impact of engine parameters on CO emission of diesel engine fuelled with Jatropha curcas oil methyl ester (JCOME). This work investigates the factors that influence the CO with lesser emission effect. Fuel injection pressure, percentage of blend of JCOME and engine load was considered as the factors for the objective and CO emission were considered as the response variables. L16 orthogonal array was prepared using design of experiments methodology and series of experimental tests were carried-out as per designed array with different combination of influencing factors. Taguchi method was applied to evaluate the influencing factors and significance of impact on response variables. The results of taguchi experiments revealed that that injection pressure 220 bar, blend BJ40 at 25% of engine load were optimum parameter setting for lowest CO emission. Engine's CO emission is mostly influenced by engine load, blend percentage of JCOME and is least influenced by injection pressure.

Keywords: *Optimization, Jatropha curcas oil, Methyl ester, Taguchi method, Biodiesel, Transesterification.*

1. Introduction

Unpredicted and day-by-day soaring prices of crude oil, energy insecurity, fossil fuel dependence on OPEC nations, ecological changes and oxides of carbon and nitrogen emissions from fossil fuels make it a high precedence to research for low-carbon alternative renewable energy sources to save money and reduce the hazardous emission effect on nature. Biodiesels are sustainable fuels, because they are produced from plant based oils such as wheat, corn, soya-beans and sugarcane (Kumar, 2012 & Shrivastava, 2012) which can be produced again and again on demand. The production of biodiesels will keep the economy secure, reduces dependence on foreign fuel imports, improves rural economy and environmentally they are non-toxic with lower sulfur content and releases less greenhouse gases than fossil fuels.

Biodiesel is basically mono-alkyl ester of long chain fatty acids derived from a renewable lipid feed-stock (Demirbas, 2008). It has more than 90% of triglycerides and trivial amounts of mono and di-glycerides and free fatty acids, besides residual amounts of phospholipids, phosphatides, tocopherols, carotenes, water and sulfur compounds (Bozbas, 2008). Eventhoug vegetabe oils have high cetane number but have higher viscosity (Zhou, 2015).

Vegetable oils can be directly used as fuel for diesel engine without modifications, but pure or partially esterified oils may lead to typical engine problems such as fuel injector plugging, piston ring sticking, long-term engine deposits, or lube oil gelling which can cause engine failure or require more frequent maintenance and shorter engine overhaul intervals (Rajesh Kumar et al., 2007). Long-term tests have exposed the fuel's limitations with respect to lubricant contamination, deposits on engine surfaces which adversely affected engine durability and performance in the long term (Bhattacharyya 1994). Crude vegetable oils releases dangerous emission gases than using diesel fuel that adversely impact on human health [Bunger, 2007]. Diesel engines emit higher NOx emission than gasoline engines due to the presence of high concentration of the local oxygen molecules (Henein, 1976). Generally, transesterification process will be used to produce biodiesel using vegetable oils which was proved to be technically feasible with less difficulties (Zang, 2003).

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The purpose of the present research study was to determine the optimum blend of JCOME biodiesel that has optimum emission values and the level of impact of engine parameters such as load, blend percentage in biodiesel and injection pressure based on the actual experimentation.

2. Materials and Methods

To apply the taguchi optimization technique, experimentation should be conducted after designing the orthogonal array by using design of experiments (DoE) methodology. Based the resulted design, series experiments will be conducted in diesel engine using the selected Jatropha curcas oil methyl ester (JCOME).

2.1 Taguchi Design and Orthogonal Array

For the present research study, three factors and four levels were chosen to study the effect of these factors on objective parameters. The engine parameters of diesel engine: fuel injection pressure, percentage of JCOME blend and engine load were considered as the factors that influencing the CO emission which is a objective responsive parameter. The list of parameters and levels are given in table 1.

Table 1 DoE – Control Parameters and Levels

Control Parameters	Level 1	Level 2	Level 3	Level 4
A. Load	25	50	75	100
B. Blend Percentage	20	40	60	100
C. Injection Pressure	210	220	230	240

In general, considerable number of experiments should conducted when the number of process parameters increases. To reduce the number of experiments to be carried-out, a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments (Yang et al., 1998). To solve this problem, the Taguchi method uses Orthogonal array of L16 was designed for the present study and was presented in table 2.

Taguchi method stresses the necessity of studying the response of variance using the signal–to–noise (S/N) ratio, resulting in the minimization of quality characteristic variation due to uncontrollable parameter (Taguchi, 1987). The less emission of CO and NOx is considered better in emission characteristics of diesel engine. Taguchi has four categorization of response variables for S/N ratio and are Larger is better to maximize the response, Nominal is best when the goal is to target the response and S/N ratio on standard deviations are required, Nominal is best when the goal is to target the response and the S/N ratio on means and standard deviations are required, and Smaller is better when the S/N ratio should be selected that best meets the objective of the optimization. In this study, the goal is to minimize the response variable (CO), and hence Smaller is better was considered to minimize the CO emission.

Table 2 Taguchi - L16 Orthogonal Array

Experiment Number	Blend Percentage (A)	Load (%) (B)	Injection Pressure (bar) (C)
1	1	1	1
2	2	1	2
3	3	1	3
4	4	1	4
5	1	2	2
6	2	2	1
7	3	2	4
8	4	2	3
9	1	3	3
10	2	3	4
11	3	3	1
12	4	3	2
13	1	4	4
14	2	4	3
15	3	4	2
16	4	4	1

2.2 Preparation of Biodiesel

Jatropha oil was collected from seeds of Jatropha Curcus using oil expeller. The crude Jatropha Curcus oil will have higher viscosity and density which creates problems to the engine and for the present work, transesterification process was used. In transesterification process, the carbonyl carbon of the starting ester (RCOOR1) undergoes nucle-ophilic attack by the arriving alkoxide (R2O−) to give tetrahedral inter-mediate, which either reverts to the starting material, or proceeds to the transesterified product (RCOOR2).

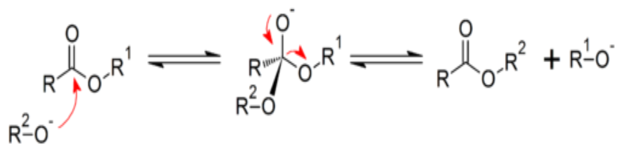

Fig.1 Transesterification Process – Chemical Reaction

After transesterification, the biodiesel characteristics like density and viscosity are comparable to that of the petrol diesel (Joshua Folaranmi, 2013, Freedman, 1986) and other chemical properties almost similar to diesel fuel.

The property of the biodiesel that was prepared from Jatropha Curcas Oil and Diesel was given in table1.

Table 1 Properties of Biodiesel (JCOME)

Fuel Property	Unit	ASTM Standards	Diesel	JCOME
Kinematic Viscosity @ 40^0C	CST	D445	3.52	5.4
Flash Point	^0C	D93	49	169
Density @ 15^0C	kg/m^3	D1298	830	870
Calofic Value	kJ/kg	D4868	42000	38450
Cetane Number	--	D613	50	53
Ash	% by mass	D1119	0.01	Nil

3. Experimental Setup

After design of orthogonal array, the series of experiments were carried-out using single cylinder, 4-stroke water cooled compression ignition direct injection (CIDI) engine fuelled with Jatropha curcas oil methyl ester (JCOME). The experiment setup is illustrated as schematic diagram in figure 2.

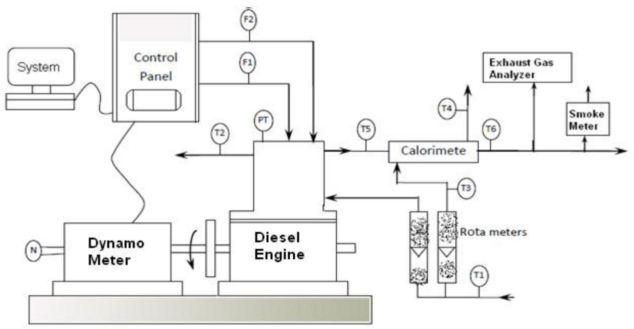

Fig.2 Experimental Setup-Schematic Diagram

The setup consist of 3.7 KW (5HP) Kirloskar diesel engine, eddy current dynamometer, smoke meter, and exhaust gas analyzer with computer test rig. The specifications of the engine are given in table 3.

Table 3 Specifications of the engine

Type	Kirloskar
Details	Single cylinder, Four stroke, DI, Water cooled
Bore & Stroke	80 × 110 mm
Rated Power	3.7 KW (5 HP)
Speed	1500 rpm
Dynamometer	Eddy Current

Series of tests were conducted on the diesel engine using JCOME as fuel with the selected engine factors at different levels to determine the effect of the engine parameter on the objective. The engine was operated 16 times with the combination of different levels of influencing factors as given in table 2. In each test the engines was tested at different loads and at each load the response: CO emission was measured using NETEL gas analyzer.

4. Results and Discussion

Taguchi design was applied for the optimization of the above mentioned three process parameters. Different combinations of three input variables: blend percentage of JCOME, load, and injection pressure were considered and one output response was obtained. In order to search for the optimal process condition with a limited number of experiments, L16 orthogonal array of Taguchi had been used as part of DoE.

4.1 Optimization of CO Emission

The analysis of Signal-to-Noise Ratio for the output response was done by using Minitab software (v17.1). Table 4 shows the experimental results of input and output parameters. Figure 3 shows the graphical representation of ratio for three influencing factors in the main effect plot for S/N Ratios and Figure 4 shows the main effect plot for Mean.

Table 4 Experimental results -S/N Ratio and Mean

Blend Percentage (%)	Load (%)	Injection Pressure (bar)	CO Emission (%)	SNRA1	Mean1
20	25	210	0.12	18.416375	0.12
20	50	220	0.09	20.91515	0.09
20	75	230	0.12	18.416375	0.12
20	100	240	0.21	13.555614	0.21
40	25	220	0.06	24.436975	0.06
40	50	210	0.1	20	0.1
40	75	240	0.14	17.077439	0.14
40	100	230	0.15	16.478175	0.15
60	25	230	0.06	24.436975	0.06
60	50	240	0.11	19.172146	0.11
60	75	210	0.1	20	0.1
60	100	220	0.1	20	0.1
100	25	240	0.07	23.098039	0.07
100	50	230	0.07	23.098039	0.07
100	75	220	0.09	20.91515	0.09
100	100	210	0.13	17.721133	0.13

If a line for a particular influencing parameter is almost horizontal, the impact of input parameter on response less significant effect will be presented as almost horizontal line in the graph. On the other hand, a parameter for which the line has the highest inclination will have the most significant effect. As show in plots (figure 3 and 4), it has been observed that engine load had the most significant effect among the three parameters followed by blend percentage of JCOME. The optimum process parameter combination corresponding to minimum emission was indicated by the max. value for signal-to-noise ratio for each input parameter. The to be BJ40 biodiesel at 25% of engine load with 220 bar injection pressure was found as optimum process parameter combination taguchi analysis.

Table 5 Response Table for Signal to Noise Ratios

Level	Blend Percentage	Load	Injection Pressure
1	17.83	22.60	19.03
2	19.50	20.80	21.57
3	20.90	19.10	20.61
4	21.21	16.94	18.23
Delta	3.38	5.66	3.34
Rank	2	1	3

(Smaller is better)

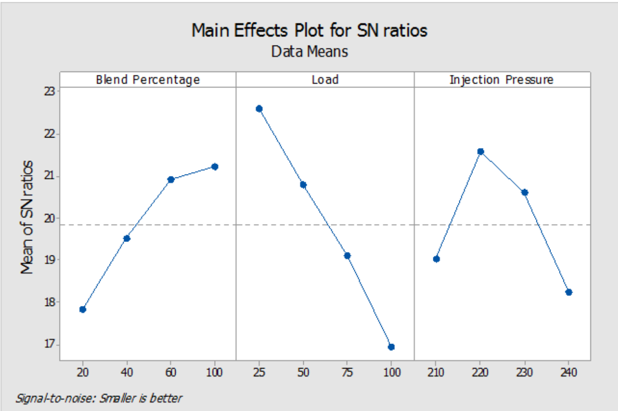

Fig.3 Main Effects Plot for S/N Ratios

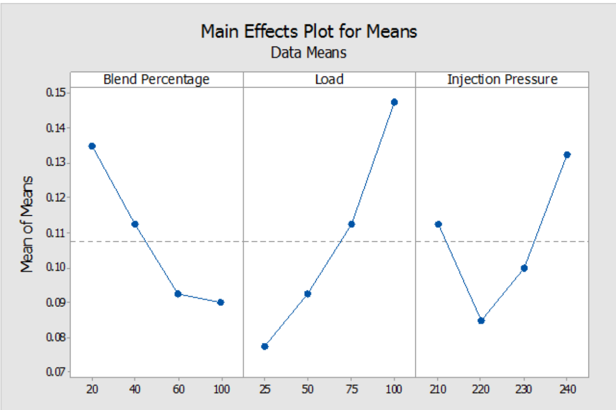

Fig.4 Main Effects Plot for Means

4.2 Validation Using ANOVA

Analysis of variance is a collection of statistical models used to analyze the differences between the group means and their associated procedures (Roy, 2001). For the present study, ANOVA was used to validate the optimized values of engine operations parameters found from taguchi analysis.

Table 6 shows the Analysis of Variance for CO emission, the F Value (18.33) of the parameter indicates the engine load is significantly contributing followed by the F value (8.75) of parameter indicates the Contribution of blend percentage of JCOME. The lowest of F value (8.08) is revealing that it has less impact on CO emission.

Table 6 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Blend Percentage	3	0.005250	0.001750	8.75	0.013
Load	3	0.011000	0.003667	18.33	0.002
Injection Pressure	3	0.004850	0.001617	8.08	0.016
Error	6	0.001200	0.000200		
Total	15	0.022300			

Conclusions

This paper investigated to determine the optimum level and effect of the experimental parameters such as load, blend percentage and injection pressure of diesel engine on carbon monoxide emission of biodiesel using Taguchi and ANOVA techniques. The experiments were carried out to evaluate the emission characteristics of single cylinder, 4-stroke compression ignition direct injection engine fuelled with different blends (BJ20, BJ40, BJ60 and BJ100) of Jatropha curcas oil methyl ester (JCOME) as biodiesel. Orthogonal arrays, signal-to-noise (S/N) ratios of Taguchi and the analysis of variance (ANOVA) were employed to find the optimal levels and to analyze the effect of the operational conditions on emission values of JCOME. The results of Taguchi experiment identifies that that Injection pressure 220 bar, blend BJ40 at 25% of engine load are optimum parameter setting for lowest CO emission. Engine emission characteristics are mostly influenced by engine load, blend and is least influenced by injection pressure. Finally finding of taguchi analysis was validated with the result obtained through ANOVA analysis and concludes the same as taguchi.

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